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CONSTRUCTION OF THE 400-KV TRANSMISSION LINES FROM KUIBYSHEV HYDROELECTRIC STATION
TO MOSCOW by D. Achksov and Y. E. Grigor'ev

from the book "FORTY YEARS OF ELECTRICAL CONSTRUCTION IN THE USSR", Gosenergozdat, 1958, pp. 373-380

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The directives of the 20th congress of the Communist Party of the Soviet Union for the sixth five-year plan of development of the national economy specify: "a unified power system must be created for the European portion of the USSR, by inter-connecting the Kuibyshev and Stalingrad hydro stations with the Central, Southern, and Ural power systems, and 400-kv lines must be built for this purpose."

The 400-kv line from Kuibyshev to Moscow which was put into service in 1956 is the first link of the unified high-voltage grid of the Soviet Union. The Kuibyshev hydro station at full capacity of 2,100,000 mw produces more than 11×10^9 kwh of electric energy in an average hydrological year. Of this quantity, it was decided to transmit more than 6×10^9 kwh per year to the Central power system by means of two 400-kv transmission lines, about 560 miles long. The task of transmitting so much power at such a distance required the solution of a series of important scientific problems by the Soviet electrical engineers.

It can be daringly said, that the construction of the 400-kv line from Kuibyshev hydro station to Moscow signifies by itself a new, higher step of Soviet electrical engineering.

Among the lines of this class, the first put into service (1952) was the single-circuit 380-kv line in Sweden, 595 miles long. The second was the Kuibyshev-Moscow line. In several other countries have been built 380-kv transmission lines, but these are now in service at 220 kv. The transition to 380-400 kv is contemplated in France and West Germany for 1957, and in Finland for 1958. In England the high-voltage grid, built for 275 kv, will have a portion for possible transformation in the future to 400 kv. In the USA a 175-mile line was energized in 1956, designed for operation at the highest voltage in that country, 345 kv.

In the over-all scheme of the transmission system from Kuibyshev hydro station to Moscow enter two single-circuit lines (the southern is 506 miles long and the northern 553 miles) with three switching stations. In one of these is specified a series capacitor of 480,000 kva. Each switching station may be expanded into a receiving 400-kv substation.

Both lines begin at the portals of the step-up substation of the Kuibyshev hydro station and end near Moscow - one at the western receiving substation (Noginsk), and the other at the northern substation (Beskudnikovo). The substations are inter-connected by means of a portion of the 400-kv future Moscow ring, 49 miles long. Thus, the over-all circuit length of the 400-kv transmission system is 1108 miles. In each of the receiving stations are installed two transformer banks 400/110/11 kv, 270 mva, and two transformer banks 220/110/11 kv, 180 mva. The installation of four synchronous condensers, 75,000 kva each is specified.

In order to improve the voltage regulation, the 400-kv and 220-kv transformer banks have series transformers with voltage regulation under load. The substations are connected to the Moscow power system at the voltages of 110 and 220 kv.

The right of way passes through mountainous territory (in the region of the Jigulevski mountains), then through rolling country and in the eastern portion, through the plains. In the neighborhood of Moscow are encountered marshy soils, impregnated with water.

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About half (48%) of the length of the right of way passes through forest clearings. There are more than 200 different crossings: railroads, highways, transmission lines, and communication lines. The intersections of the river Ok and of the Usinskii reservoir of the Kuibyshev sea required construction of heavy crossings. For the construction of the two single-circuit lines and of the substations, it was necessary to complete the following principal work, in total

Earth removal	3,400,000 m ³ (cubic meters)
Pouring concrete	320,000 m ³
Erection of towers	4,365 pieces
Building of metal structures	62,700 metric tons
Stringing conductors and ground wires	32,500 metric tons.

In the process of construction, a communication line 548 miles long was laid, villages were built at the substations and switching stations with clubs and schools (two lines of photostat unintelligible). . . . about 34,000 m² (square meters) of living quarters, temporary constructions, warehouses, . . . temporary roads and access roads, etc.

The first foundation of a tower of the southern line was laid on April 30, 1952. The last tower of the northern line was erected on October 20, 1956. Relatively short times of construction were obtained as a result of the adopted industrial methods of construction and the use of labor-saving machinery of powerful modern engineering.

For the industrialization of construction it was necessary to provide: the delivery of the heavy sections of the tower, welded in the factory, and the assembly of these elements on the site; construction of houses in the settlements from prefabricated assemblies; the use of devices and riggings for the erection of the towers, which became part of the towers, etc.

The heavy work on the line was almost completely mechanized. More than 90% of the earth-moving work was done mechanically, and all the work for the erection of the towers and the preparation of the concrete. The times allowed for construction determined the necessity of starting work at the same time at several places, as often occurs for the construction of a long line. Thus in a 236-mile portion of the Finnish 380-kv line, construction was started at the same time in four places.

For the Kuibyshev-Moscow line, nine points were established before starting construction, as field construction headquarters or installation sections.

The main feature of the construction was the novelty of almost all its elements. The weight and the dimensions of the towers were essentially different from those used previously. A typical H-frame suspension tower of the 400-kv line (Fig. 1) weighs 7.3 metric tons and has a width at the crossarm of 89 feet. The weight of a strain-angle tower (Fig. 2) of the new A-H-frame beam construction is from 19 to 29 tons, depending upon the angle of the line..

Bundle conductors were adopted for the first time in this line, and this reduced the line reactance by 35 - 39%. Each phase consists of three conductors of type ASO-480/60 (1.19" O.D., 954 MCM - P.A.A.), built by the manufacturing industry specially for the Kuibyshev-Moscow transmission system. Similar important elements, such as the clamps releasing under load and the spacers, installed between conductors, were tested at the time of construction.

Service experience showed that it was necessary to change the original location

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of the spacers, and therefore it was requested to move about 70,000 spacers on already strung spans.

The trust "Armset" designed more than 150 types of fixtures, including the new insulators type P-8.5 and P-11, specifically for the 400-kv lines. All the apparatus of the 400-kv substations was designed anew by the electrical manufacturing industry. Transformers, air-blast breakers, synchronous condensers, disconnect switches, protective devices went into production at the time of construction of the lines and substations.

The novelty of the basic elements required new methods of work, at times significantly different from those used for the construction of lower voltage lines.

For the suspension towers, a monolithic foundation was specified in the plans, with a volume of concrete of about 60 m^3 and earthwork (with the excavation of two trenches and subsequent filling) of about 300 m^3 . For the construction of the foundations a considerable amount of wood was used in the forms. During the process of construction the monolithic foundations were changed into low-volume rammed foundations, significantly simpler and more economical. As may be seen in Fig. 3, the suspension tower is erected on eight separate foundations, each one having in its lower portion a tapered enlargement.

The amount of concrete for foundations of this type was reduced to 15.5 m^3 per tower. Inasmuch as the concrete was poured (was rammed) in a hole, bored into the ground by a machine, it was not necessary to use forms. The use of concrete in combination with soil of unbroken structure allowed to increase the specific load on the soil. Foundations of the same type were also used for the strain-angle towers.

The factory "Setmash" designed and put in production in a very short time the boring machine type B-8, which allowed the almost complete mechanization of the earth-moving work for the construction of the rammed foundation. As the monolithic foundations, also the rammed foundations required the preparation of the concrete on the site. Experience showed that the creation of separate concrete centers, furnishing concrete for the foundations of a predetermined section of the right of way, was more economical and efficient, than the so-called "laying concrete at each site."

Each concrete center consisted of two or three concrete mixers, with container capacity of 250 liters, mounted on trucks. For ease of loading of the ready concrete mix, concrete mixer trucks were filled at a bridge. The center was furnished with a mobile electric substation, with conveyors for loading the materials, etc. For the supply of water, tank trucks type ASM-2 of capacity of 2 m^3 were used for the first time in line construction. The simple construction of these machines, permitting filling up the tanks using the vacuum of a primary mover, made it possible to fill up the tanks by pumping the water in the soil from a trench.

The radius of a concrete center is determined by the presence and conditions of the roads. One of the centers which worked to a large distance serviced 10 miles of right of way and produced $3,000 \text{ m}^3$ of concrete. The auto concrete mixers, which were used for laying concrete at the site according to the direction of the workers, were supplied with various accessories. Some were provided with "distributors" of concrete, which permitted supplying the mix at any point of the trench in a radius of 5 meters from the unit. Such a distributor did the work of 4 or 5 men.

Among the machinery were established electric portable generators in sufficient number. These supplied power to the electrical vibrators and permitted work to continue at night.

Considerable attention was given to the questions of laying concrete in winter.

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Different methods were used for warming the trenches and laying concrete by electricity, stoves, etc. More successful was the experience of heating of the cylindrical trenches of the rammed foundations. Mobile substations were built for the heating of the materials and of the water. For this purpose it was attempted to use narrow-gage steam locomotives.

However, the over-all result showed that laying concrete in winter for foundations of small volume is clearly not economical, and does not guarantee the required quality. This conclusion led to the decision of abstaining completely from working with concrete on the right of way in winter. Of the total amount of towers, 52% was set on foundations of the rammed type, and 12% of metallic supports with - -(photostat illegible). The latter types were used in the wet and marshy portions of the right of way.

The earth-moving work was done by excavators, mostly with bucket capacity of 0.25 m^3 , of type E-257 and E-258, and with boring machines. The use for line construction of excavators with bucket capacity of 0.5 m^3 and higher is not rational, because their productivity on the right of way was equal to 2 - 3 towers per day (in view of the inconvenience of moving them from site to site) that is, it is equal to the productivity of the light excavators with 0.25 m^3 buckets.

The construction of the steel towers, produced by several factories in welded sections of length equal to 29 feet, was undertaken at locations close to the railroad. After completion the towers were carried to the site and erected by a gang of 5 - 6 men.

Thorough painting and straightening of the sections and of the struts, bent during transportation, was done on the site during assembly. The towers were painted with red lead over natural drying oil.

The erection of the suspension towers was done with the aid of two S-83 tractors linked together, without anchors for straightening the tackle. In several sections of the line the method was used, whereby upon attaining a predetermined angle of lift, one tractor resorted to braking action.

All of the tackles used for the erection of the tower became part of the tower itself, that is they had a permanent device for holding the tower and embedded fastenings. No supports were used on location.

In the last period of construction of the towers, in order to accelerate the fastening of the cables for lifting, permanent connection plates with lugs were introduced. The raising of the heavy strain-angle towers was done with 2 - 3 tractors for lifting and two tractors for braking.

To take care of the lift, the towers were strengthened during assembly with horizontal crossbars between the ends of the legs, and with cross-tension members, which gave stiffness along a line. The tension members were removed after erection and fastening of the fifth leg of the tower. A stage in the assembly of an AU tower is shown in Fig. 4.

The inspection of the towers proceeded with increased requirements. The deflection of the top of the 89-foot tower was permitted to be no more than 3.2 inches, the error in length between the angle brackets between braces of the towers no more than 0.2 inches, the error of the struts no more than 1:400 in length.

Special difficulties arose in constructing the line crossings across the Usinskii reservoir of the Kuibyshev sea. The crossing of each single-circuit line consists of four anchor towers. Two of these have a height of 66 feet and weigh 100 metric tons each. The other two standing on the shore of the reservoir have a

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height of 228 feet and weigh 320 tons each. The span over the water between the high towers is 3,730 feet. Steel-bronze conductors (two per phase) of Model SB-500 and ground wires of 134 mm² cross-section were strung for the crossing.

Construction of the foundations for the high crossing tower was a difficult engineering problem (for one of the foundations whose surface was 89' x 75' it was necessary to excavate more than 13,000 m³ of earth and to set up 183 tons of metal armatures). Concrete was carried by means of small cars to the foundations from a temporary concrete factory especially set up for this job.

Taking into account the heavy weight and height of the crossarms, the method of vertical assembly was used for their erection. The erection was made by a specialized organization using various basic machinery.

The first sections of the towers were erected by a crane on the base of a single-bucket excavator E-1004. The following sections of the tower were erected by means of a derrick 98 feet high, after the sections had been strengthened on the ground. The height of the derrick was gradually adjusted to the height of the tower. In order to lift the crossarm 112 feet long and weighing more than 40 tons, previously assembled completely on the ground, two swinging derricks were used, secured with special cantilevers to the pillars of the tower.

The raising of the crossarm was done with tractors S-60, using two tractors at each end of a one-half ton pulley block. Mountainous conditions limited the maneuverability of the tractors. After they had proceeded for 500 - 700 feet, it was necessary to lock the cables, turn the tractors around and move them again on the same terrain. The erection of the pillars of the towers on the pins was completed in 2.5 months, the preparation for the lifting of the crossarm required about one month. The drilling and riveting of 160 angle pieces on the towers already erected required 1.5 months. The work was carried out under difficult circumstances.

The Kuibyshev - Moscow line is the first one having each phase subdivided into three bundle conductors, and length between the strain towers of 4 - 6 miles. There had been no previous experience in stringing the conductors under these conditions. As work proceeded and more practical experience was attained it was possible to string the conductors faster and with better quality.

For stringing operations were prepared balanced wheels on roller bearings with reversible flanges; a fixture for suspending three such wheels (according to the number of conductors per phase) to the crossarm of the tower; block and tackles for lifting the conductors to the towers; a device for equalizing the tension in the three conductors of one phase during stringing. On a special test stand were tried out various types of spacers of national and foreign production in order to select the best construction. The following data expresses the difficulty of stringing the conductors: one gang strung the conductors on the line on no more than 6 - 9 miles per month.

For the transportation and unrolling of the conductors on the right of way, the construction gangs received cable conveyors and later they, themselves, prepared stringing trucks with three containers. The use of these devices eliminated the necessity of dragging the conductor on the earth which would have brought about damage to the outer strands of the conductor and at the same time would have increased the corona losses and the radio noise. The stringing truck is composed of a platform mounted on caterpillar tracks or on sleds. On the platform are placed three containers (Fig. 5). Changing one container does not require the shifting of the other two.

The containers are loaded with a tractor using a device in the form of a fork.

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Fixing the ends of the fork to a shaft mounted on the container, the tractor rolls the container onto the trailer. The trailer permits unrolling up to 18 containers (6 miles of one phase) per day. The joining of the conductors is made by means of a pressing apparatus mounted on a trailer (Fig. 6). This apparatus is powered by a gasoline engine, and this simplified and hastened the preparation of more than 20,000 junctions and releasing clamps. For checking the location of the steel portion in the press-clamp ORGRES furnished a simple and reliable device.

One of the fundamental operations of stringing was subjected to review and to simplification, that is the marking on the conductor of the place for setting the releasing clamps.

Each tower of the line Kuibyshev - Moscow carries 9 conductors, (three conductors per phase) and two ground wires. On each conductor this marking was generally carried out from the crossarm of the strain tower. According to suggestions of the efficiency experts of construction, only one conductor was lifted to the crossarm and marked on top. Afterwards the received mark was transferred to the ground and the eight remaining conductors were marked according to that mark without being lifted to the crossarm. This measure simplified the work of the stringing crew and increased the preservation of the conductors.

The purpose of the spacers is to maintain the given spacing between conductors of one phase (16") and the elimination of contacts between conductors during swinging. For the line Kuibyshev to Moscow a ball and socket spacer was used (Fig. 7) which would fall down in case of breakage of one conductor. The spacers were placed in groups, every 100 to 200 feet.

At the time of construction it was established that placing the spacers to avoid bending must be done on the conductors after stringing. A truck type VI-23 with a raised platform was used for this work. A suspended cabin, specially designed for the installation of the spacers, was not used extensively.

The suspension insulator assemblies consisted of 22 insulators and had a total length of more than 16 feet. It was recommended to assemble them by the method of gradual build-up of their . . . (unreadable), lifting up at one time the portion already assembled (Fig. 8). During the assembly it was noticed that the in-going holes of the insulator scarfs were turned towards the pedestal, as required by the maintenance personnel. Inasmuch as the assemblies with three conductors in one span weigh more than three tons, the usual straps for lifting them, attached under the porcelain of the insulator, appeared to be unsatisfactory. For the line construction, straps were used with screwed bars, fastened on the insulator caps.

The strain insulator assemblies, having a length of more than 23 feet and weight of about 2600 lbs., were put together by the same method of gradual build-up. Special attention was required in order to maintain on all spans a balanced setting of the conductors in a phase with a tolerance not exceeding the specifications. The construction and stringing work were approved by an inspection commission at the strain towers after a compulsory inspection by the chief engineer of the section or of the trust.

The energization of the line proceeded in sections from the 400-kv supply point of Moscow. At the same time the work of installation in substations and the switching stations was inspected.

Receiving substations

The immediate construction of the eastern substation was begun in March 1953 and

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was completed for the first section in November 1955, that is, the work continued for two years and seven months. In this period was accomplished preparatory work, intermediate accommodations were erected, living quarters for the workers, and an access highway.

The over-all station, measuring 10,800,000 square meters in surface, included outdoor structures for 400, 220, and 110 kv, buildings for the main control switch boards, two blocks for synchronous condensers and a block for transformer work shop, oil storage and laboratory. For the transportation of the transformers having an over-all weight of 320 tons and of the synchronous condenser, a special railroad siding on reinforced concrete was built outside each station.

For the construction of the substation it was necessary to prepare 3500 different foundations with an over-all volume of more than 38,000 m³ concrete, it was necessary to assemble 2700 tons of metal structures, prepare 920 meters of cable tunnels and 4100 meters of cable ditches and to complete 450,000 m³ of earthwork. The completion of such volumes of work in a relatively short time required the fulfillment of a strict sequence of work. In the first stage were built the underground main piping systems and the foundations and other buildings, the engineering facilities, and the permanent roads. The earthworking for the many foundations was done with excavators, with creation of a general trench. This gave the possibility to clean out the bottom by means of bulldozers and facilitated the removal of high waters in the soil. - - - (unreadable photostat) - - - After the preparation of the foundations the metal structures of the bus bars were erected, and then the apparatus was set up according to a planning chart.

The toughest work of assembly was the assembly of the 400-kv transformers. They were delivered from the factory in separate portions of limited weight or clearance. This made it necessary to carry out on the area of the stations operations of factory character. In the substation took place the assembly of sections of the tank, the welding of the supporting channels, the testing of the tank for leaks and its painting, etc. The heart of the transformer (the core and the windings) weighing 150 tons was sent from the factory in a transport tank. On location it was dried under vacuum, impregnated, and assembled. In order to complete this work at the eastern substation a transformer work shop was erected with a crane of 200 tons capacity and a special vacuum-drying tank. Taking into account the high cost of the work, no vacuum-drying tank was used in the northern station and the core and coils of the transformer were dried in the tank of the transformer with a special winding.

For the assembly of the synchronous condensers of 75,000 kva in the outdoor station, a method of erection without cranes was used. The separate portions of the condenser were brought to the foundations by a railroad siding, on a special transport car consisting of a supporting platform and moving trucks. The platform loaded with the stator or with the rotor of the condenser was moved from the truck across the rails, fell on the mounted platform of the foundation so that the upper mark of the foundation exactly coincided with the references on the platform. In this manner the heaviest load on the railroad car was moved (on top of the reinforcements on the foundation) only on the horizontal plane.

The assembly of the first circuit breakers and disconnect switches for 400 kv was not a simple matter.

In order to judge the difficulty of this assembly work it is sufficient to show that a 400-kv disconnect switch has a weight of 6 tons per phase, is 17 feet high and the length of a leg is 16 feet. An air breaker (Fig. 12) of the type VV-400 has a height of 39 feet, a length of 29 feet, and a weight per phase of 17 tons. - - - (unreadable photostat) - - -

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The northern station was completed in 23 months, eight months faster than the eastern.

In April 1956 was begun the permanent transmission of energy from the Kuibyshev hydro station to Moscow on the southern circuit. Power was received at the eastern station (Fig. 10). On the 30th of December 1956 the northern circuit of the line was energized, the northern station and a portion of the 400-kv Moscow ring. The Soviet electrical engineers have attained a new victory. Energy from the Volga flows to Moscow on the 400-kv lines without interruption.

The experience obtained in the construction of the transmission lines from Kuibyshev to Moscow has allowed the constructors and assemblers to undertake the construction of 500-kv lines of the same dimensions from Kuibyshev hydro station to

Zlatoust with substations in Bugulme and Zlatoust, having a right of way 470 miles long and a construction period of 1.5 years. The work for the construction of this line is being carried out on all sections by six construction trusts and is proceeding according to plan. The extensive construction and installation contract for the construction of two circuits of the transmission line at 500 kv from Stalingrad to Moscow, at 500 kv from Zlatoust to Sverdlovsk will also carry out the construction of transmission lines at 400 kv from Novo-Troitskaya hydro electric station to Sarbai.

In this manner the construction of the transmission lines from Kuibyshev to Moscow was the beginning of the construction of long lines of the unified high voltage grid of the European portion of the Soviet Union. Their outlines are now visible not only on maps or on plans, but also in reality on the rights of way.

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FIGURE CAPTIONS

1. Suspension tower of the 400-kv line from Kuibyshev Hydro Station to Moscow.
2. Strain tower of beam construction.
3. Foundation of a suspension tower of the 400-kv line.
4. Erection of a strain angle tower of the 400-kv line.
5. Stringing truck.
6. Pressing apparatus for connection conductors.
7. Ball and socket spacer for 400-kv lines.
8. Installation of the suspension insulator strings.
9. Yokes with screw coupling.
10. Western substation.

THE USE OF 500-KV VOLTAGE FOR
LONG-DISTANCE POWER TRANSMISSION

By A. D. Romanov and N. N. Sokolov

(Elektricheskie Stantzii, May 1958, pp. 55-59)

The level of the sustained power frequency voltages for the insulation of the apparatus and lines of the transmission system from the Kuibyshev Hydro Station to Moscow, and of the other 400-kv systems of the Soviet Union, was determined by taking the magnitude of the internal overvoltages equal to 3 U (U = line-to-ground voltage).

Tests made in 1956 by the VEI (All-Union Electrical Engineering Institute of Moscow) on the Kuibyshev-Moscow transmission system, have shown that actually the level of the internal overvoltages varies in the range 1.6 - 3.0 U. Thus, without stations of longitudinal compensation (i.e., series capacitors) on the 400-kv line, the VEI tests gave the following results:

1. The opening of an unloaded 400-kv transformer, either on the 115-kv side, or on the 410-kv side, is accompanied by overvoltages not exceeding 2 U.
2. Upon opening a 150-mva reactor, its overvoltages amounted to 1.8 - 2.5 U: the corresponding overvoltages on the contacts of the circuit breakers attained 1.8 - 3.2 U.
3. The opening of an unloaded line 117 - 635 km in length produced overvoltages at the source of 400 - 670 kv: in this case the overvoltage level at the breaker contacts attained 2.8 U, and from the line conductors to ground 2.3 U.
4. The most severe conditions take place when an unloaded portion of the line, 390-km in length, is opened during a single-phase short-circuit and the reactor is disconnected. In this case the line overvoltage before opening was 940 kv, and during the opening process the overvoltage level on the healthy phases of the line attained 2.8 U, and on the breaker contacts it was of the order of 4 U. When the reactor was present on the disconnected portion of the line, the overvoltage level on the breaker attained 3.1 U.
5. The interruption of transmission by means of the breaker of the East sub-station led to an increase of voltage at the end of the line of 2.2 U. If, during the interruption of transmission and loss of synchronism of the generators at the Kuibyshev Hydro Station, the opening takes place under phase opposition, the overvoltage level on the breakers attains the magnitude 3.5 U, and at the end of the line 2.6 U.
6. Closing an unloaded line 117- and 390-km in length to the transformer bank entails overvoltages at the beginning of the line of levels 1.6 and 2, respectively. For the 390-km length, the overvoltage at the end of the line attains the level 2.4. The presence of a reactor on the end of the 390-km line lowers the overvoltage level at the beginning of the line to 1.8, and at the end of the line to 2. Thus the tests confirmed the presence in many cases of levels of internal overvoltages less than 3 U.

Investigations carried out recently showed that the internal overvoltages in transmission lines may be limited to magnitudes of the range of 2.5 U, utilizing means which are technically possible and economically justified. These means are: shunting of the breaker contacts by active resistances, the shifting of electromagnetic potential transformers on the line behind line breakers, shunting of the series capacitor installation until the short-circuit in the line is opened; the installation on the line of shunted reactors which are not disconnected (wherever this is possible accord-

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ding to the operating conditions). Whenever the stated means are insufficient the limitation of internal overvoltages to $2.5 U$ may be obtained by means of special arresters.

Furthermore, the present 400-kv substations have some reserves in the insulation with respect to the standards. Thus, the insulator chain chosen for the Kuibyshev-Moscow transmission line (22 elements P-7 or 20 elements P-8.5) has a wet discharge voltage of 900 kv and an impulse discharge voltage of the order of 2,000 kv. Some reserves in the insulation are also present in the 400-kv apparatus, as may be seen in Table I.

TABLE I

Voltage	Wet Discharge Voltage, kv		Test Voltage, kv		Dry Discharge Voltage, kv, According To Test Data
	Nominal	According To Test Data	Standard	According To Test Data	
Current Transformer	700	800	-	-	1,100
Disconnect Switch:					
To ground	700	856	-	-	975
Between Contacts	-	-	1,150	1,300	-
Circuit breakers	700	780	-	-	906

There are reasons to believe that there are additional reserves also in the main insulation of the power transformers.

The preceding considerations are the over-all basis of the previously taken decisions of reducing the insulation requirements of the 400-kv lines and apparatus, or else of maintaining in practice the same insulation and increasing the nominal transmission voltage to 500 kv. The 500-kv voltage was selected on the basis that the insulation of the existing apparatus and that the line insulation will be at 500 kv practically under the effect of the same overvoltages that exist at 400 kv with $3 U$, since the level of internal overvoltages is lowered to $2.5 U$ at 500 kv.

The idea of lowering the level of internal overvoltages below $2.5 U$ by using special arresters does not seem possible at the present time, because of the difficulties encountered in the creation of such an arrester.

The arrester must have a small difference between the sparkover voltage and the seal-off voltage. Preliminary specifications for the characteristics of the arrester working on a 500-kv current may be set as follows: breakdown voltage of the spark gaps of the arrester at power frequency should be 960-kv maximum (680-kv eff.) which corresponds to a level of internal overvoltages equal to $2.3 U$.

The arrester must allow during 1 - 2 semiperiods the flow of currents of 1.5 - 2 ka, with an arrester voltage not to exceed 700-kv eff. ($2.4 U$).

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The seal-off voltage of the arrester U_{ex} must be chosen possibly lower, in order to make easier the conditions of extinction of the arc in the spark gap. Nevertheless a marked lowering of U_{ex} may produce a failure in the operation of the arrester, because the voltage at the end of an unloaded line during the fault conditions may be higher. Therefore the seal-off voltage of the arrester must be chosen in the range 470-490-kv eff. (1.63 - 1.7 U) and it is desirable to increase it to 520 - 580-kv eff. (1.8 - 2.0 U).

A further reduction of the insulation level of the installations, originating from low magnitudes of the internal overvoltages (or the increase of the nominal voltage of the 400-kv installations beyond 500 kv) may appear very difficult considering the working conditions of the insulation under the influence of the operating voltage. This case is specially related to the external insulation, which during service may be subjected to contamination.

The reduction of the specifications for the apparatus insulation, set for the stations and substations, and of the line insulation permits reduction of the cost of 400-kv installations.

The increase of the nominal transmission voltage to 500 kv gives the following advantages:

a) it increases the transmission capacity, with respect to stability, by 40% or, for the same specified transmission capacity, it allows reduction of the size, and sometimes to eliminate completely the need, of special means for increasing stability (series capacitors, intermediate synchronous condensers, etc.);

b) it reduces the energy losses due to heating of the line conductors.

In addition to this the voltage increase, even for a 2.5 U-level of internal overvoltages, leads to some improvement of the apparatus (with respect to the present 400-kv apparatus) related to the necessary changes of its construction or parameters. However, the use of the existing conductor configurations for transmission at 500 kv significantly increases the energy losses due to corona on the lines. Therefore, the question of the advisability of increasing the nominal transmission-line voltage from 400 to 500 kv, or of reducing the specifications of the 400-kv installations, should be decided on the basis of over-all technical and economical investigations.

A technical and economical comparison of transmission at 400 and 500 kv is discussed below, based on the example of change-over to 500 kv of the 400-kv transmission from Kuibyshev to Moscow, from Stalingrad Hydro Station to Moscow, and of the 400-kv circuits of the Urals, according to the work done by the Division of Long-Distance Transmission V.G.P.I. of the Thermal Project.

An appraisal of the economical effectiveness of increasing the voltage is based upon the comparison of the capital investments and of the yearly operating expenses for different values of the transmission capacity. A comparison of the technical and economical parameters of transmission at voltages of 400 and 500 kv is based upon two sets of values for the insulation levels of 400-kv installations - 1) for 400-kv voltage the existing apparatus and line insulation, determined for 3 U, is used; the apparatus and line insulation for 500 kv is determined for 2.5 U. 2) The line insulation and apparatus for 400 and 500 kv is determined for 2.5 U, that is, the 400-kv installations are assumed to be reduced in relation to the existing installations.

For the determination of the line cost, structures were worked out with 3 x ASO-480 conductors (phases subdivided into 3-bundle conductors) on the basis of the factors discussed above. The fundamental results of these studies are given in Table II.

TABLE II

Parameters of Lines With Conductors 3 x ASO-480

<u>Parameters</u>	<u>For Voltages</u>		
	<u>400 kv</u>		<u>500 kv</u>
Level of internal overvoltages	3.0	2.5	2.5
Ground clearance, feet	26.2	24.5	26.2
Distance between phases, feet	33.5	30.5	36.0
Height of towers, feet	89	89	89
Length of span, feet	1300	1400	1300
Number of insulators, suspension string	20	17	20
Cost of 1 km of line, thousand rubles	299.3	288.3	301.0

It is seen in Table II, that the present 400-kv lines, designed for a level of internal overvoltages of 3 U, and the 500-kv lines have practically the same cost (the difference is about 2,000 roubles/km). If the insulation of the 400-kv lines is reduced, these cost less than the 500-kv lines by 13,000 roubles/km, which corresponds to about 4% of the cost of the construction of 1 km of line. For other conductor cross-sections, the difference in cost is less.

The present and already planned 400-kv lines may be transformed to 500 kv with very small investments. The capital investments for the apparatus of the 400- and 500-kv lines were determined according to the increased parameters of the cost of construction of an open distributed layout.

In the computations it was assumed that the cost of the circuit-breaker unit at 500 kv will be 7% higher than the cost of a unit of the existing 400-kv apparatus. The cost of a 500-kv transformer would be 5% higher (for the same type of power transformer).

In comparing the 500- and 400-kv portions, the nominal (passing) power of the autotransformers was assumed to be the same. Thus, the physical power of the 500-kv autotransformers is higher than the power of the 400-kv autotransformers, and this was taken into consideration in the additional cost of the 500-kv autotransformers.

In the solution with reduced level of internal overvoltages of 2.5, the 400-kv apparatus was reduced in cost with respect to the present apparatus, 5% for the circuit-breaker units and 15% for the transformers.

In Table III are given the data for the over-all costs of the basic apparatus.

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TABLE III

Cost of Basic Apparatus

<u>Apparatus</u>	400 kv		500 kv
	<u>3 U</u>	<u>2.5 U</u>	<u>2.5 U</u>
Autotransformers, rubles/kva			
for W = 270 mva, $U_2 = 110$ kv	21.0	17.8	23.6
for W = 500 mva, $U_2 = 220$ kv	14.5	12.3	19.9
Transformers, rubles/kva			
for W = 370 mva, $U_2 = 13.8$ kv	29.2	24.8	30.6
Circuit breakers, millions of rubles/unit	3.7	3.52	3.96
Series capacitor for 400 kv, rubles/kva	105	105	-

For the determination of the yearly operating losses, amortization, maintenance, and repair are taken into account: for the lines 4%, for the substation apparatus 8%.

The energy losses are taken into account only in the lines, inasmuch as the energy losses in the substation apparatus would be about the same in first approximation at 400 and 500 kv. The ranges of power losses due to corona are given in Table IV.

TABLE IVAverage Annual Power Losses Due To Corona
3-Phase kw/mile

Operating Voltage, kv	3 x ASO-400		3 x ASO-480	
	Distance between subconductors of a phase; inches			
	16	24	16	24
400	3.2	3.9	2.1	2.4
420	4.3	5.6	3.1	3.5
480	12.6	15.0	8.4	10.1
500	16.5	20.1	11.6	13.7

For the determination of the yearly losses due to corona it was assumed that the transmission lines operate half the time at voltages of 420 or 500 kv, and that for the rest of the time they operate at 400 or 480 kv.

The transmissions which have been considered may be separated into two types:

- (1) Main double-circuit transmission for Stalingrad Hydro Station to Moscow with relatively few intermediate power taps and with a heavy load factor ($T_{\max} = 5,000$).
- (2) Branch circuit of the Ural type with relatively low transmitted power, but with the possibility of a short-time considerable increase of the transmitted power in separate portions of the circuit.

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For the transmission from the Stalingrad Hydroelectric Station to Moscow, the transmitted power was taken to be in the range of 1,200 mw.

For the 400-kv voltage, the transmission capacity of the transmission line according to stability consideration was guaranteed by means of a series-capacitor installation. For higher transmission capacities it was guaranteed by means of a sufficient number of intermediate synchronous condensers.

For the 500-kv voltage in the transmission line from Stalingrad Hydro Station to Moscow, it was possible to avoid series capacitor installations and for a transmitted power exceeding 1,500 mw, stability was guaranteed by means of synchronous condensers.

For the Ural circuits special means would be required to increase stability only for the section Kuibyshev Hydro Station to Chelyabinsk. The transmitted power on the main section of this line varied in the range 550 - 900 mw, with no change in the magnitude of the transmitted energy (2.7×10^9 kwh).

In Table V are given the technical parameters which pertain to two types of transmission discussed here.

TABLE V

<u>Parameters</u>	<u>Stalingrad-Moscow</u>						<u>Ural Circuit</u>					
Transmission capacity, mw	1200		1500		1800		550		700		900	
Voltage, kw	400	500	400	500	400	500	400	500	400	500	400	500
<hr/>												
Series capacitor												
X_c , ohm	23	-	48	-	48	-	-	-	60	-	60	-
Q, mva	231	-	630	-	939	-	-	-	180	-	180	
<hr/>												
Synchronous condensers, 75 mva each, number	-	-	-	-	6	6	1	-	1	-	3	3
<hr/>												
Losses on the lines, 10^6 kwh/year												
due to I^2R	262	185	410	290	590	417	86	61	118	84	143	100
due to corona	32	130	32	130	32	130	31	119	31	119	31	119
total	294	315	442	420	622	547	117	180	149	203	174	219
Ratio $\frac{\text{corona losses}}{I^2R \text{ losses}}$	0.12	0.70	0.08	0.45	0.05	0.31	0.36	1.95	0.26	1.42	0.22	1.19

The resulting economic parameters were established on the basis of curves of changes of the capital investments and operating expenses for increase of the transmission voltage from 400 to 500 kv (Figures 1 and 2).

Analysis of the data of Table V shows that at 500 kv the energy losses due to corona abruptly increase. These losses represent a substantial portion of the energy losses due to I^2R for loaded lines and they exceed the losses due to the load for relatively low loaded lines. At 500 kv it is expedient to consider the change of the line conductors to a larger diameter (non-expanded and so-called expanded conductors with a filler of non-conducting material). In order to equalize the energy losses due

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to corona on the 500-kv lines to those of the 400-kv lines with conductors 3 x ASO-480 (conductor diameter 1.119")*, the diameter of the expanded conductor should be about 1.45".

However, it might be more expedient to consider the subdivision of each phase into 4 subconductors.

The comparison of the technical and economic parameters of a 2-circuit transmission at 400 and 500 kv leads to the conclusion that the increase of the nominal transmission voltage of a main line of 800 - 1,000 km in length is economically advantageous for transmitted power per circuit exceeding 650 - 700 mw.

According to Swedish data published in the 1956 CIGRE reports, the transition to 500 kv is justified when it is necessary to increase the transmission capacity to 750 - 800 mw per circuit or higher. For the operating periods of the Ural circuits with relatively small magnitudes of transmitted power, the transition to 500 kv gives an overexpenditure in capital investments of 20 - 30 million rubles. This is 3 - 5% of the total investment for the line and apparatus of open-distributed constructions 400 - 500 kv, and increases the yearly operating expenses by 8 - 20%.

On the basis of the data given above, and taking into account the intensive development of extra-high-voltage systems and the increase of the power transmitted on these systems, the Ministry of Electric Stations of the U. S. S. R. made the decision to convert the existing and designed 400-kv systems to a nominal voltage of 500 kv, and to design new long-distance transmission lines for a nominal voltage of 500 kv. The correctness of this decision is further supported by the following considerations. After the long-distance transmissions from Stalingrad Hydro Station to Moscow and from Kuibyshev Hydro Station to the Urals had been constructed, a unified power system for the European portion of the U. S. S. R. was created which connects in parallel operation the most powerful power systems of the Southern, of the Center, and of the Urals.

In the conditions of a unified power system, it is not necessary to have the same requirements of transmission capacity of long-distance transmission, as for isolated transmission from a far away hydro station to a receiving system.

It is much more difficult to guarantee the stability of parallel operation of a unified power system, particularly in the first stages of its development, up to the emergence of a sufficient number of links, than for an isolated transmission.

The stability calculations of the unified power system made for the Thermal Project, the works of Tz. N.I.E.L., N.I.I.P.T., E.N.I.N. A.N. U.S.S.R. have shown that the requirements of transmission capacity of the connecting links must be higher than for isolated transmissions. This is explained by the fact that the functions of the connecting links already exist for long-distance transmission, loaded with powers which are constantly transmitted from the hydro station to the receiving system. In unification of systems by means of interconnecting links, equalizing currents will constantly flow which may preliminarily attain a magnitude of 2.2%, a very small portion of the power of the power systems which they interconnect. For the line Moscow-Kuibyshev-Urals, additional overcurrents may attain 400 mw. This certainly requires a further increase of the transmission capacity of the transmission systems. A much more economical and technically simpler way of achieving this is to increase the voltage from 400 to 500 kv.

*Note: This corresponds to 954 MCM per conductor ([REDACTED])

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The increase of the transmission capacity of the transmission lines from Kuibyshev to Moscow and to the Urals is necessary also as a consequence of the increase of the power of the Kuibyshev Hydro Station (increase of the working capacity of the turbines, installation of additional apparatus) and the interconnection to these lines of the Saratov and Lower Kama Hydro Stations.

For the Kuibyshev to Moscow transmission lines, the change-over to 500 kv increases the transmission capacity from 1,350-1,400 to 1,800 mw with the existing series-capacitor installation. It increases the efficiency of transmission from 90 to 91.5% (for transmission of 1,800 mw, 9×10^9 kwh energy), it reduces the cost of transmission of power by 8% (the cost of transmitting energy is about 2 kopecks/kw).

The investments for the change-over to 500 kv of the Kuibyshev-Moscow lines will be approximately 60 million roubles. In this amount about 20 million roubles are required for the rebuilding of the 400-kv apparatus of the hydro station. A basic portion of this investment is due to rebuilding of the transformers (replacement of the 400-kv windings of the transformers and autotransformers with 500-kv windings). The change-over to 500 kv increases the power of the transformers of the 400-kv receiving substations in Moscow from 270 to 340 mwa. This will be obtained by reconnecting the 400-kv and 110-kv windings of the installed transformers to autotransformer connection. Additional expenditure due to the transition to 500 kv will be paid off in 4 years.

For the rebuilding of the existing 400-kv apparatus for the 500-kv voltage, relatively little work will be required: the mounting of additional elements for the air-breakers, for the arresters, for the potential transformers, for the coupling capacitors, and some other work.

In order to guarantee a transmission capacity of 1,800 mw, the 400 kv on the Kuibyshev Hydro Station to Moscow transmission, it would have been necessary to build a second series capacitor installation, and to install an additional 400-kv transformer in the receiving substation in Moscow. The cost of this construction could attain approximately 60 - 70 million roubles.

For the transmission lines Kuibyshev Hydro Station to the Urals, the change-over to 500 kv increases the transmission capacity from 600 to 900 mw (in the principal portion) without a series-capacitor installation, and to 1,200 mw with a series capacitor. At 500 kv it is not necessary to construct additional circuits from the Votkinsk and from the Lower Kama Hydro Stations. This would have been required at 400 kv in connection with the increase of the capacity of these hydro stations.

For the transmission lines from Stalingrad Hydro Station to Moscow, the transmission capacity of 1,500 mw may be guaranteed at a nominal voltage of 500 kv without special means of increasing stability, such as series capacitors or intermediate synchronous condensers. In this manner, the circuits and the construction of intermediate substations are simplified significantly.

For the voltage increase from 400 to 500 kv, the capital investments for the transmission from Stalingrad Hydro Station to Moscow are reduced by 70 million roubles, or by 5%. The transmission efficiency is increased from 91.4 to 92.2% and the cost of transmitting power is reduced from 1.92 to 1.66 kopecks per kw, or by 13.5%.

For the basic circuit of Central Siberia with calculated currents corresponding to 700 - 800 mw per circuit or higher, the change-over to 500 kv reduces the capital investment per circuit by 6% and the power losses by 26%.

Thus, the increase of the voltage of long-distance power transmission from 400 to 500 kv appears to be a progressive measure which will permit the realization of a unified electric power system of the Soviet Union with optimum technical and economic characteristics.

FIGURE CAPTIONS

Figure 1 - Economic parameters of transmission of the type Stalingrad - Moscow at 400 and 500 kv, for different overvoltage levels (2.5 and 3).

1. Capital investment;
2. Annual operating expenses.

Ordinates: capital investments, millions roubles; operating expenses, millions roubles. Abscissae: transmitted power, mw.

Figure 2 - Economic parameters of the Ural circuit for change-over from 400 to 500 kv.

1. Increase of capital investments (for a level of assumed comparative investments 590 - 680 million roubles).
2. Increase of operating expenses (for a level of comparative expenses 41 - 58 million roubles).

———— K = 3 for 400 kv and K = 2-1/2 for 500 kv

- - - - K = 2-1/2 for 400 and 500 kv

Same ordinates and abscissae as Figure 1.

The Use of 500-kv Voltage for
Long-Distance Power Transmission
By A. D. Romanov and N. N. Sokolov

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4-6-59

in 400KV all equip built in USSR

500KV eqm

transformers & circuit breakers built by USSR in 7

Switzerland

500KV auto transformer

don't know why they need to France

But, know how to do it but don't have facilities

TRANSLATION OF "USE OF SMALLER INSULATORS FOR 110-500 KV TRANSMISSION LINES"

By A. N. Sherentzis (Elektricheskie Stantsii #4, 1959, pp. 54-59)

In 1958, the "ARMSET" trust organized the large-scale production of smaller porcelain suspension insulators of the type PM-4.5. These insulators will be employed instead of the presently widely-used insulators P-4.5.

In the last 2-3 years, the mass production of smaller porcelain insulators was planned with increased electromechanical quality, corresponding to the quality of the present insulators P-8.5 and P-11. It is also necessary to note that the Scientific Research Institute For Glass together with the All-Union Electrical Technical Institute and also the Lvov Polytechnical Institute prepared the experimental samples of smaller insulators of hard glass, designed for electromechanical one-hour test loads in the range from 4.5 to 20 metric tons. In the present article the questions which refer to the use of smaller insulators for transmission lines from 110 to 500 kv are discussed. This is in connection with the imminent widespread use of these insulators in the USSR.

Electric and Electromechanical Characteristics of the Insulators of Type PM-4.5

The insulators of type PM-4.5 are designed for a one-hour electromechanical test load of 4.5 tons. In their construction they are similar to the insulators of type P-4.5 and they are manufactured from the same porcelain. However, they have a lower height--that is, a height of 140-142 mm (5.5 - 5.6") instead of 170 mm (6.7") of the insulator P-4.5. The reduced height is obtained by means of a change of the form of the cap of the insulator (Fig. 1).

The determination of the electrical insulation characteristics of the small porcelain insulator of type PM-4.5 was made at the All-Union Electrical Technical Institute (VEI). The test program included the determination of the wet flashover voltages at power frequency of strings including a different number of elements, and determination of the impulse flashover voltages for the standard wave form.

Below are given, according to the data of the VEI, the electrical and electromechanical characteristics of the insulators of type PM-4.5, and for comparison also the characteristics of the type P-4.5.

TABLE I

<u>Characteristic</u>	<u>Type Insulator</u>	
	<u>PM-4.5</u>	<u>P-4.5</u>
Height, mm	140	170
Diameter of the skirt, mm	270	270
Weight, kg	5.6	6.5
Electromechanical disruptive load, tons	6.0	6.0
Electromechanical one-hour test load, tons	4.5	4.5
Voltage, kv:		
Dry flashover	75	75
Wet flashover	45	40

As a result of these tests, it was established that the average wet flashover gradient of a string of insulators PM-4.5 is 2.7 kv/cm, that is about 15 per cent higher than for a string of insulators P-4.5. This is due to the fact that because of the decrease of the

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height of the cap, the arc does not cascade as previously, but instead proceeds through the air between the edges of the skirt.

As well known, the impulse flashover voltage is proportional only to the length of the string and is independent of the form of the suspension insulator. The results of the tests at the VEI have shown that the average impulse flashover gradient of positive polarity for the insulator PM-4.5 has the same range as that of the insulator P-4.5.

Basic Considerations for the Insulation and Lightning strength of 110-500-kv Transmission Lines With Smaller Insulators

The requirements for the insulation of transmission lines are determined by the magnitude of the maximum long-duration operating voltage, by the rated level of the internal overvoltages, and by the level of lightning strength of the transmission line.

Calculations which have been made have shown that for 110-500-kv transmission lines with insulators P-4.5 and P-8.5, the insulation determined from the operating conditions of the internal overvoltages, guarantees the necessary protective levels for atmospheric overvoltages, for towers which have been grounded according to criteria of sufficient economy.

In order to determine the required number of smaller insulators, a similar method was used. The number of elements was determined for the wet flashover voltage of the line insulation, corresponding to the rated level of the internal overvoltages which had been established for the 110-500-kv lines. Then it was verified that the chosen number of insulators corresponded to the requirements of the lightning strength of transmission lines having the towers grounded as usual. The verification of the lightning strength was then made according to the method given in the Standard Instructions for the protection from overvoltages. In accordance with the initial data given above, calculations were made for the determination of the number of elements in a string of smaller insulators. In the calculations it was assumed that smaller porcelain insulators of type PM-4.5 would be used for 110-330-kv transmission lines, but that insulators PM-8.5 of 170-mm height would be used for the 500-kv lines.

The results of the calculations for the determination of the number of elements in a suspension string of smaller insulators for lines with steel or re-inforced concrete towers are given in Table I.

TABLE I

<u>Item</u>	<u>Data for Nominal Voltage, kv</u>				
	<u>110</u>	<u>150</u>	<u>220</u>	<u>330</u>	<u>500</u>
Wet flashover voltage, kv	220	300	430	580	775
Insulator height, mm	140	140	140	140	170
Number of elements per string	7	9	13	16	20

Because of the possibility of having defective insulators, the number of elements in the suspension strings of 110-300-kv transmission lines was increased by one. For 500-kv transmission lines, this number was increased by two. For 110-220-kv wood-pole transmission lines, the number of insulators is reduced by one.

In accordance with the new Regulations for the construction of substations, the number of insulators in a strain string of smaller insulators is increased by one with

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respect to the suspension string, for lines up to 110 kv. For lines of nominal voltages of 150-kv and above, the number of insulators in the suspension and strain strings must be the same.

The use in service of mixed strings, consisting of insulators P-4.5 and PM-4.5, requires special experimental verification. This is due to the fact that unfavorable arrangements of these types of insulators in a string may reduce somewhat the flashover voltages.

In connection with the obtained increase of the wet flashover gradients of the smaller porcelain insulators, the number of smaller insulators chosen according to the rated level of internal overvoltages, remains the same as the number of the insulators of the present type. Although the wet flashover gradient of the smaller insulators is considerably higher than that of the insulators P-4.5 and P-8.5, nevertheless the impulse flashover gradient, as was already noted above, remains the same as that of the other type of insulators. Therefore, as may be seen from Table II, the level of lightning strength of a transmission line with smaller insulators is reduced.

TABLE II

<u>Item</u>	<u>Data for Nominal Voltage, kv</u>				
	<u>110</u>	<u>150</u>	<u>220</u>	<u>330</u>	<u>500</u>
Level of lightning resistance for insulators of usual types, ka	135	155	215	285	320
Level of lightning resistance for smaller insulators, ka	100	115	175	200	235

Note: The levels of lightning strength are shown for an impulse ground resistance of 8 ohms, which corresponds to 12-15 ohms measured at power frequency.

For comparison, calculations are also made of the lightning strength of 110-330-kv transmission lines with insulators P-4.5, and of 500-kv lines with insulators P-9.5. All calculations of the lightning strength were made for the same initial conditions and for towers with two ground wires. In all calculations the impulse flashover gradient of the string was taken to be equal to 5.5-kv.m/cm, with some margin. The calculations were concluded with the determination of the level of lightning strength of transmission lines with a given level of impulse strength of the tower insulation and with different magnitudes of the ground resistance.

The results of the calculations, given in Fig. 2 and in Table II show that use of smaller insulators, for the same magnitude of the ground resistance, reduces the level of lightning strength of the 110-150-kv lines by about 25 per cent. Instead, 330-500-kv transmission lines with smaller insulators and towers normally grounded practically remain completely lightning-proof, and 220-kv transmission lines may have a very small relative number of faults, because their protective level remains quite high and is about 175 ka.

It is necessary to note that reduction of the level of lightning strength of 110-220-kv transmission lines with smaller insulators should not be a reason for increasing the number of elements in the string in order to bring up the impulse strength to the previous value. The calculations which have been carried out have shown that this method of increasing the impulse strength is not very effective, because it increases the lightning strength in relatively small steps and at the same time it causes additional expenses. Furthermore, it is necessary to observe that the absolute number of lightning

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faults remains at a very low level, as before. Furthermore, the progress obtained in the field of applying automatic reclosing allows, at the present time, a significant reduction of the requirements of the lightning strength of transmission lines. It is known that in the USSR and in some foreign countries, at the present time, extra-high-voltage lines are operating with ground wires installed only in the neighborhood of the stations. There is, for instance, the first circuit of the 220-kv transmission system from the Kamskii Hydro Station to Sverdlovsk, which was put in service without ground wires: To date the 1956 lightning season had 20 lightning flashovers, nevertheless there were no interruptions of service because the lightning flashovers were successfully liquidated by means of automatic reclosing. On the Bonneville Electric System (USA), the entire 220-kv system is normally operating with ground wires only in the neighborhood of the stations.

The increase of the lightning resistance of transmission lines may also be accomplished more economically by reducing the ground resistance of the towers. It is necessary to note that in good conducting soils ($\rho \leq 3 \cdot 10^4$ ohm cm) a reduction of the magnitude of the impulse ground resistance up to 6 ohms does not correspond to practical difficulties and to any noticeable increase in the cost of construction. Therefore, whenever smaller insulators are used for transmission lines whose right of ways have good conducting soils, it is necessary to try to reduce the magnitude of the impulse ground resistance to 5-6 ohms which corresponds to 8-10 ohms at power frequency. Then the protective level, as is shown in Fig. 2, will attain levels which are characteristic of the levels of transmission lines with insulators of the usual type. In soils with high specific resistance, where the ground resistance cannot be reduced to the values given above, the best means of lightning protection is automatic reclosing, which permits operating normal transmission lines with a relatively poor protective level. This method is equally effective when using smaller insulators.

In conclusion, it is necessary to point out that all the considerations and results of calculations of lightning strength given above refer to towers not higher than 30 meters (98 ft.). Transmission lines with towers higher than 30 meters are not very frequent in USSR systems, and have been used only recently. Nevertheless it is possible to establish that the use of smaller insulators will not entail any increase in the number of flashovers on high towers. Service experience shows that in this case it is very effective to use two ground wires for which the number of the lightning flashovers of the lines on high towers is reduced to less than 1/2 or 1/3.

Determination of the Minimum Permissible Separation Between Conductors

Rules for the construction of electric stations recommend that the minimum permissible separation between conductors of transmission lines should be determined according to two design conditions: (1) according to the coming together of the conductors in the span, and (2) according to the conditions of insulation coordination.

Furthermore, the separation between conductors must satisfy the requirements of the safety codes. Calculations* have shown that for standard 110-220-kv towers, the distance between phases determined for the conditions of the conductors coming together in the span, is more than would be required for insulation coordination. Insulation coordination on the tower contemplates a choice of distances between phases and to the body of the tower, so that when the string is swung by wind of a given velocity the minimum flash-over distance in air will be electrically equal to the insulation of the line. Consequently, smaller insulators, which allow a reduction in the length of the string, give the possibility of a reduction in the distance between phases, if this distance is determined by insulation coordination considerations.

*A. N. Sherentzis, Elektricheskie Stantsii, #11, 1950

Translation

TABLE III

5.

<u>Item</u>	<u>Data for Nominal Voltage, kv</u>				
	<u>110</u>	<u>150</u>	<u>220</u>	<u>330</u>	<u>500</u>
Length of string of usual porcelain insulators, mm (ft.)	1190 (3.9)	1530 (5.0)	2210 (7.25)	2720 (8.9)	4080 (13.3)
Length of a string of smaller porcelain insulators, mm (ft.)	994 (3.25)	1278 (4.2)	1850 (6.1)	2240 (7.3)	3230 (10.5)
Reduction of the length of the string due to the use of smaller insulators, mm, (ft.)	200 (0.65)	250 (0.8)	360 (1.15)	480 (1.6)	850 (2.8)
Reduction of string weight due to the use of smaller porcelain insulators, kg	5.7 (12.7%)	7.4 (7.7%)	10.6 (12.7%)	14.4 (14.0%)	- -

For 110- to 220-kv lines, the use of smaller insulators leads to a certain reduction in the length of the strings, as shown in Table III. This permits a corresponding reduction in the distance between phases. Nevertheless, it is necessary to note, as discussed above, that for 110-220-kv lines the distance between phases, as a rule is determined by the coming together of the conductors in the span. Consequently, the use of smaller insulators essentially cannot introduce a reduction of the distance between phases. The greater diameter and weight of the conductors for 330-500-kv lines excludes the possibility of nonsynchronous coming together of the conductors, and consequently the necessity of determining the distance between conductors of different phases by taking into account the swing of the conductors due to the wind. Therefore, the distance between phases of 330-500-kv lines is determined by the requirements of insulation coordination. This circumstance gives the possibility of using very effectively the smaller insulators for extra-high-voltage lines. Thus, calculations have shown that on 500-kv towers, smaller insulators allow a reduction of the string length of 0.85 meters (2.8 ft.). This, in turn, gives the possibility of reducing the distance between the phases by about 0.4 meters (1.3 ft.).

Technical - Economical Advantages of Using Smaller Insulators

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As a result of the above, the weight of the 500-kv portal towers calculated for the second climatic region and the wind velocity of 27 m/sec is reduced by about 5 per cent, and even more for a wind velocity of $v \geq 30$ m/sec. Even if the height of the tower is the same, the use of smaller insulators allows increase of the design span taking into account that a relatively small increase of the span practically does not cause an increase of the weight of the tower. Calculations have shown that for 110-kv lines the design span is increased by about 1 per cent and practically does not entail a reduction of the number of towers in the line. For 220-330-kv transmission lines, the reduction of the length of suspension strings allows a reduction of the design span of 6-8 m and reduces the number of towers by 1.5-2 per cent. For 500-kv lines in the second climatic region, the design span may be increased approximately by 15-20 m and consequently the number of towers is reduced by 3-4 per cent.

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It is also necessary to note that the use of smaller insulators allows the use of previously-built 110-220-kv towers for lines of higher nominal voltage. It also gives the possibility of satisfying the requirements of insulation coordination for a varied range of special towers of lines which have been transformed to an increased nominal voltage. Thus, for instance, a typical two-circuit at 220-kv tower with hexagonal configuration of the conductors may be used for 330-kv lines, if smaller insulators are employed. In those cases where the transformation of transmission lines to higher nominal voltages cannot be made because of lack of clearance, it may be advantageous to change the insulators on these lines from the normal to the smaller type, and thus satisfy the requirements for the insulation distances between conductors and to the ground.

Operating Advantages of Smaller Glass Insulators

Finally, it is necessary to note the operating advantages of smaller insulators made of hard glass, which have found wide application in foreign countries on lines of all nominal voltages. The service experience of glass insulators has been completely satisfactory.

In the USSR, it is very desirable to proceed as soon as possible to the production of smaller insulators made of hard glass, designed for electromechanical test loads in the range of 11-16 tons.. In fact, the production of smaller porcelain insulators for test loads above 11 tons presents significant technological difficulties.

A study shows that smaller insulators of hard glass, designed for electromechanical loads of 16-20 tons, allow, in most cases, avoidance of double strings for transmission lines with bundle conductors. Furthermore, these insulators are advantageously applied on strain towers, inasmuch as the reduction of the length of the string and the number of strings gives the possibility of simplifying the construction of the strain towers. On the basis of data in the literature, it is possible to say that the service reliability of transmission lines with hard glass insulators will not be less in all cases than the reliability of lines with porcelain insulators. The high mechanical strength of hard glass insulators is especially to be noted. This permits reducing significantly the number of mechanical damages to the insulators during transportation and installation, and also during service. A special characteristic of hard glass insulators is that during an electrical puncture they shatter into minute particles and that the mechanical strength of the remainder of the insulators is sufficient to prevent the falling of the conductor onto the ground.

This characteristic of glass insulators significantly simplifies the prophylactic control on transmission lines and reduces the operating expenses, because it is no longer necessary to make special measurements on the insulators which require significant expenditure of time and means. In order to determine the location of the damage, a visual method may be employed and personnel of relatively low qualifications.

Conclusions

1. Suspension insulators which have been built up to the present time are excessively large, with respect to size and weight. Because of this, it is necessary to work out new designs of smaller insulators.

2. In 1958, "ARMSET" began the mass production of smaller porcelain insulators of type PM-4.5. These are made of the usual porcelain and are similar in design to the insulators of type P-4.5, but they have a height of about 140 mm (5.5") instead of 170 mm (6.7") for the P-4.5 insulators.

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3. The use of smaller insulators PM-8.5 on 500-kv lines allows reduction of the distance between phases to 10.1 meters (33.1 ft.), of tower weight by about five per cent, and of tower height by 0.85 meters (2.8 ft.). The weight of a string of insulators on 110-500-kv transmission lines is reduced by 12-15 per cent.

4. Following are additional advantages of the use of smaller insulators on transmission lines: the possibility of using previously built towers for lines of higher voltage; the avoidance of the use of double strings on transmission lines with bundle conductors; the simplification of the construction of strain towers by reducing the length of strings and the number of strings; and lower transportation expenses during the construction of transmission lines.

5. The mass production of suspension insulators of hard glass will give the possibility of significantly improving the mechanical and electrical characteristics of the insulators and at the same time of significantly reducing their height. It is recommended that insulators of this type be made of nonalkaline glass or of glass with low alkali content, not having in its composition materials which will be difficult to obtain. As soon as possible, it is advantageous to proceed to the production of smaller insulators of hard glass, designed for mechanical test loads of 11-16 tons.

Translated by [REDACTED]
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FIGURE CAPTIONS

Fig. 1. General view of an insulator of type PM-4.5 [height 140 mm (5.5"),
width 270 mm (10.6").]

Fig. 2. Level of lightning strength of 110- to 500-kv transmission lines

----Usual insulators

—Smaller insulators

(ordinate ka; abscissa ohms; curve parameters kv)

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